BNL Advanced Accelerator Group
FFAG Studies

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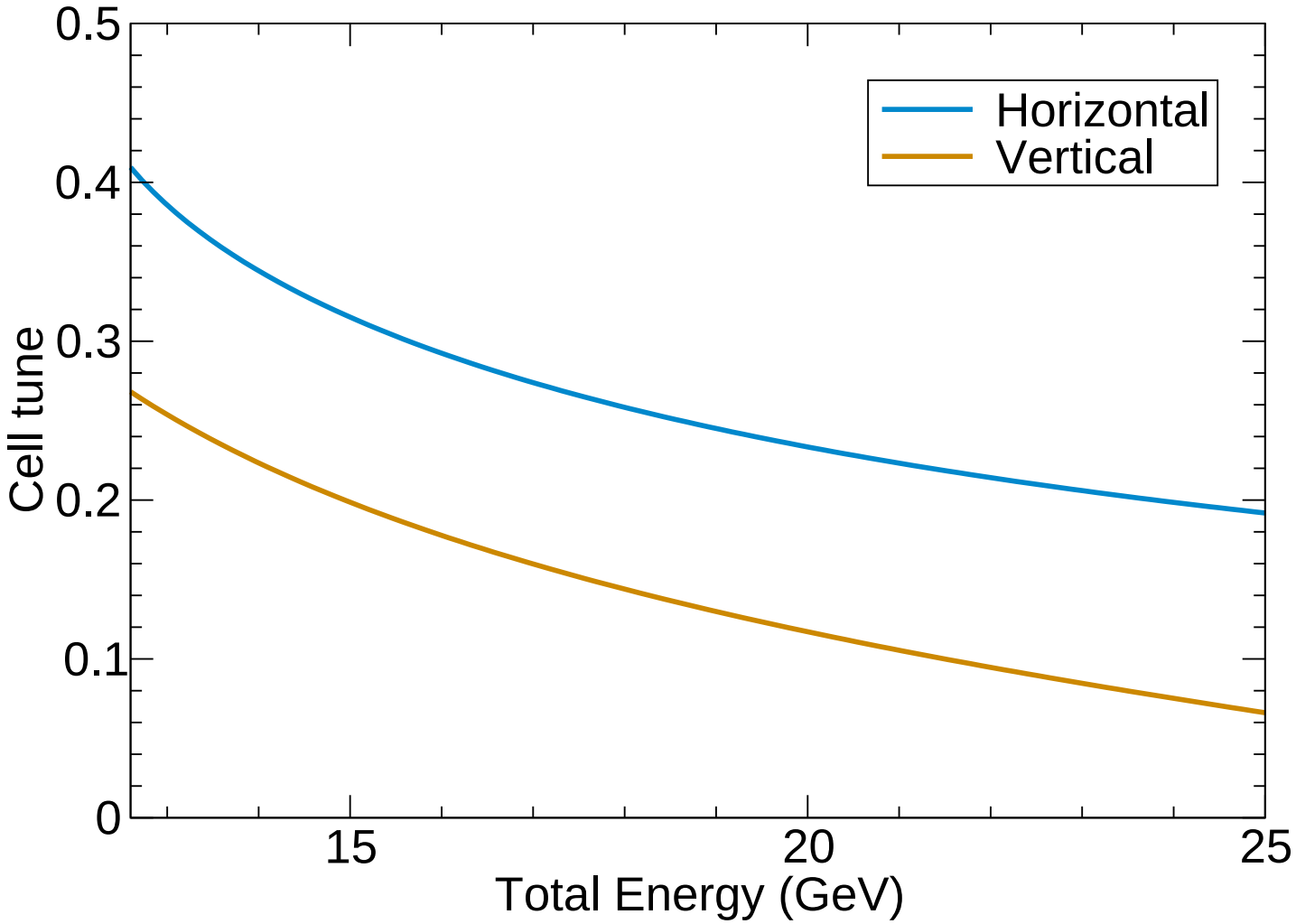
FFAG Introduction

- **F**ixed **F**ield **A**lternating **G**radient accelerator
- Large energy range (factor of 2 or more) with single arc
- **F**ixed **F**ield: don’t ramp magnets
- **A**lternating **G**radient: reduced aperture (compared to cyclotron)

FFAG Introduction
Scaling and Non-Scaling

- Original FFAG: scaling
  - Tunes fixed, dynamics independent of energy
  - Nonlinear magnets, but good dynamic aperture
- Linear non-scaling FFAG (used in NF/MC)
  - Apertures smaller than scaling
  - Less time variation with energy than scaling
  - Tunes vary with energy
  - Linear magnets give large dynamic aperture

Tune of Variation with Energy



Motivation for FFAGs in Muon Accelerators

- Want efficient, low-cost acceleration
- Multiple passes through RF
- Recirculating linear accelerators: switchyard limits passes
- Must accelerate rapidly (decays)
- No time to ramp magnets (at lower energies)

Wider Applications of FFAGs

- Anywhere one wishes to avoid magnet ramping
- Reduced aperture from cyclotrons
- Applications
  - High power proton drivers
  - Accelerator driven systems (subcritical reactors)
  - Medical accelerators

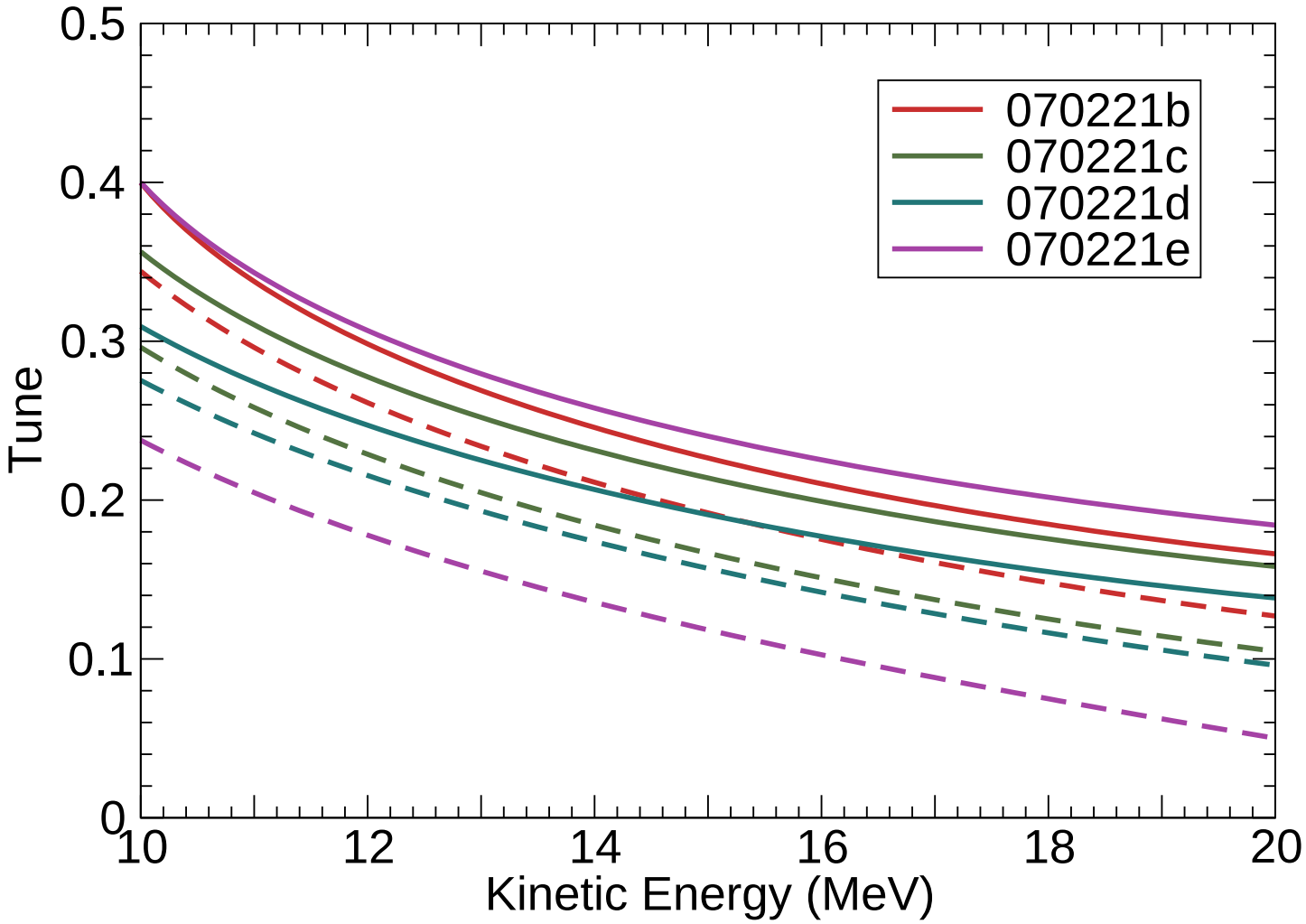
Advanced Accelerator Group
FFAG Work

- Theoretical studies
- EMMA experiment
- Muon collider acceleration

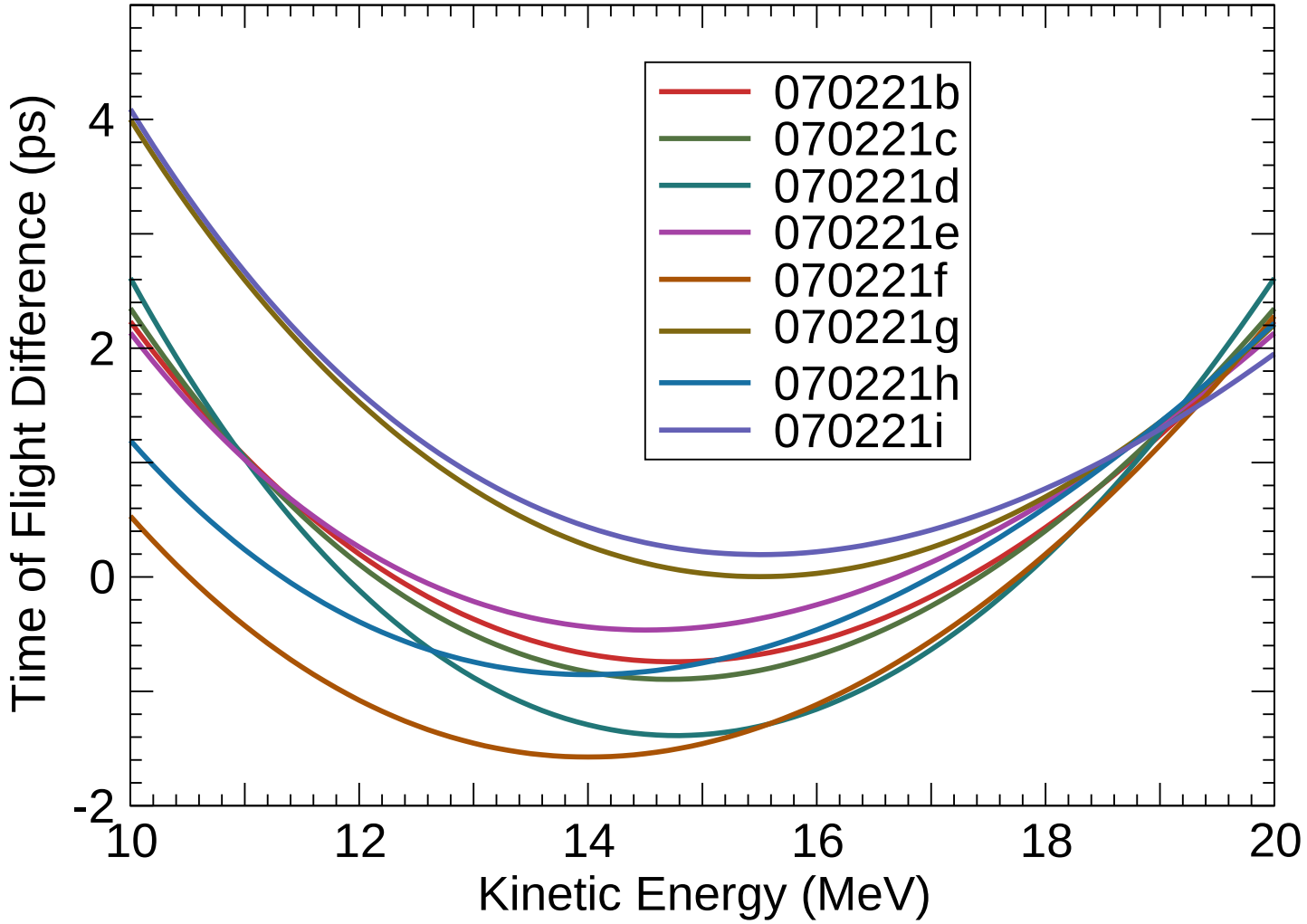
EMMA Experiment
Experiment Goals

- Demonstrate a first non-scaling FFAG
- Study single-particle dynamics in linear non-scaling FFAGs
  - Verify closed orbit properties vs. energy
  - Study longitudinal dynamics
  - Study effects at large transverse amplitude
- Vary lattice and longitudinal dynamics parameters

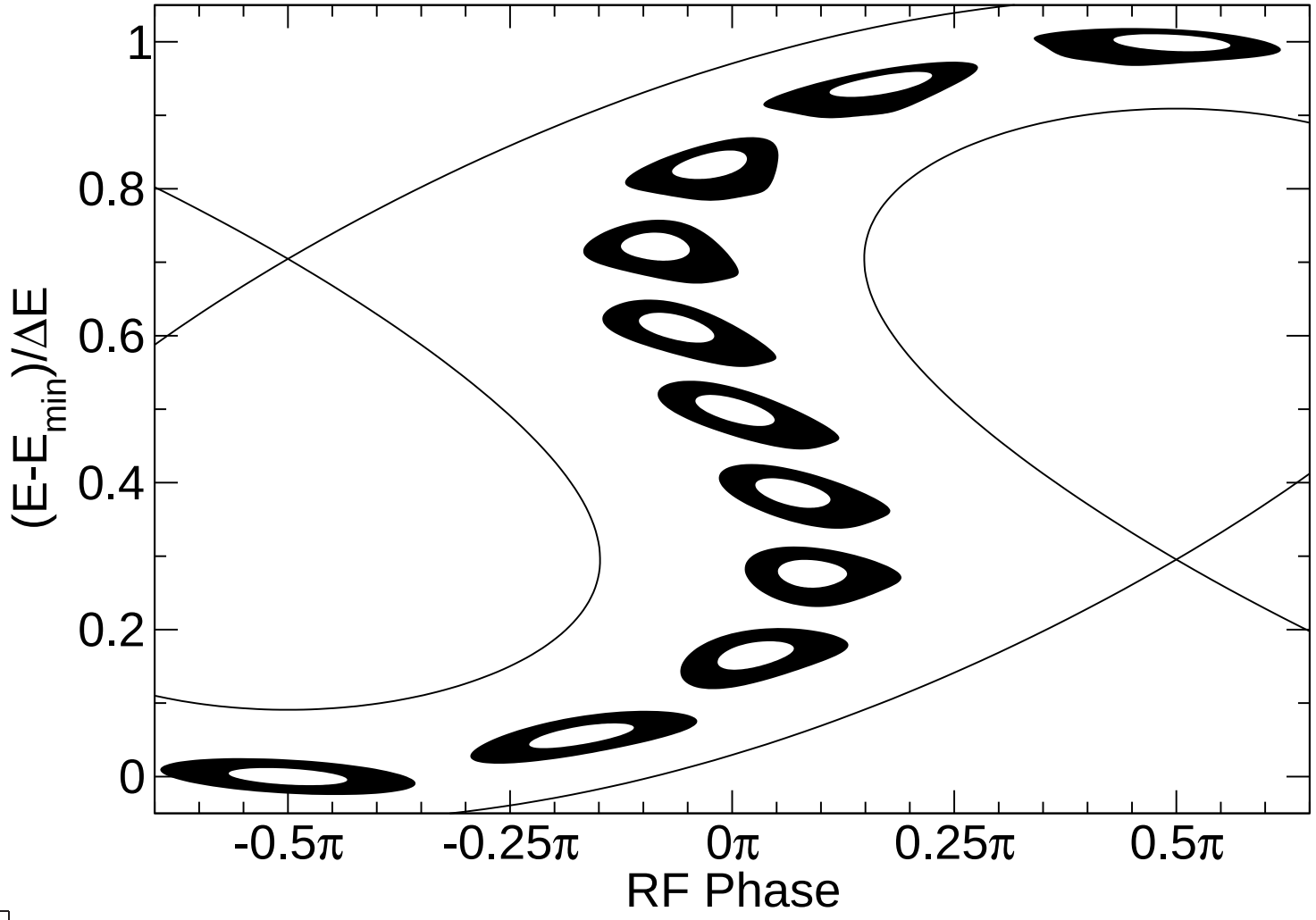
EMMA Experiment
Tunes



EMMA Experiment
Time of Flight



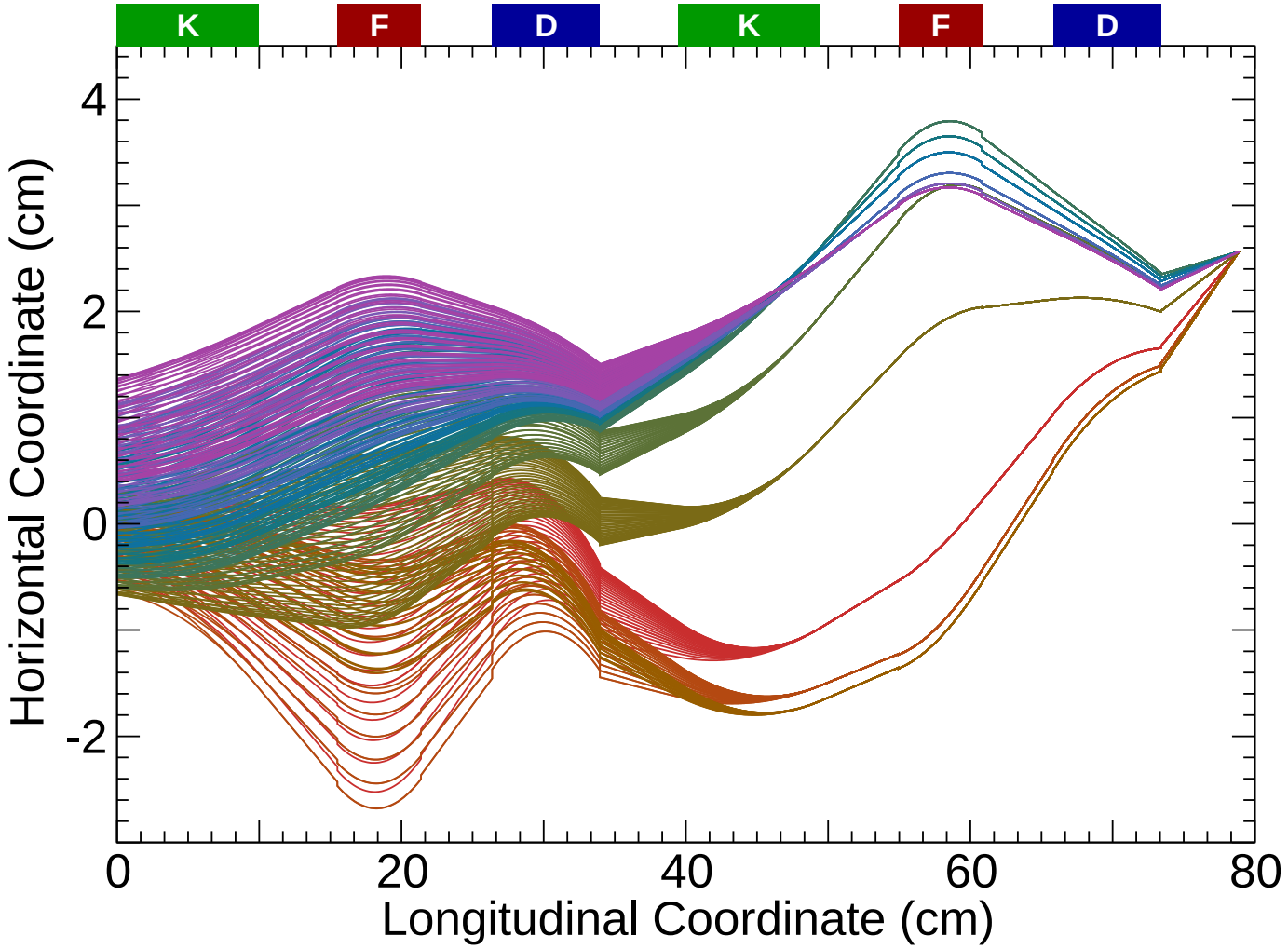
EMMA Experiment
Longitudinal Dynamics



EMMA Experiment
Our Contributions

- Design of main ring
- Specified requirements for range of lattices
  - Magnet displacement and strength variability
  - Cavity tuning range and maximum voltage
  - Magnet, cavity, and pipe apertures
  - Requirements for uniformity
- Described experiment plan
- Showed how one can inject/extract at all energies

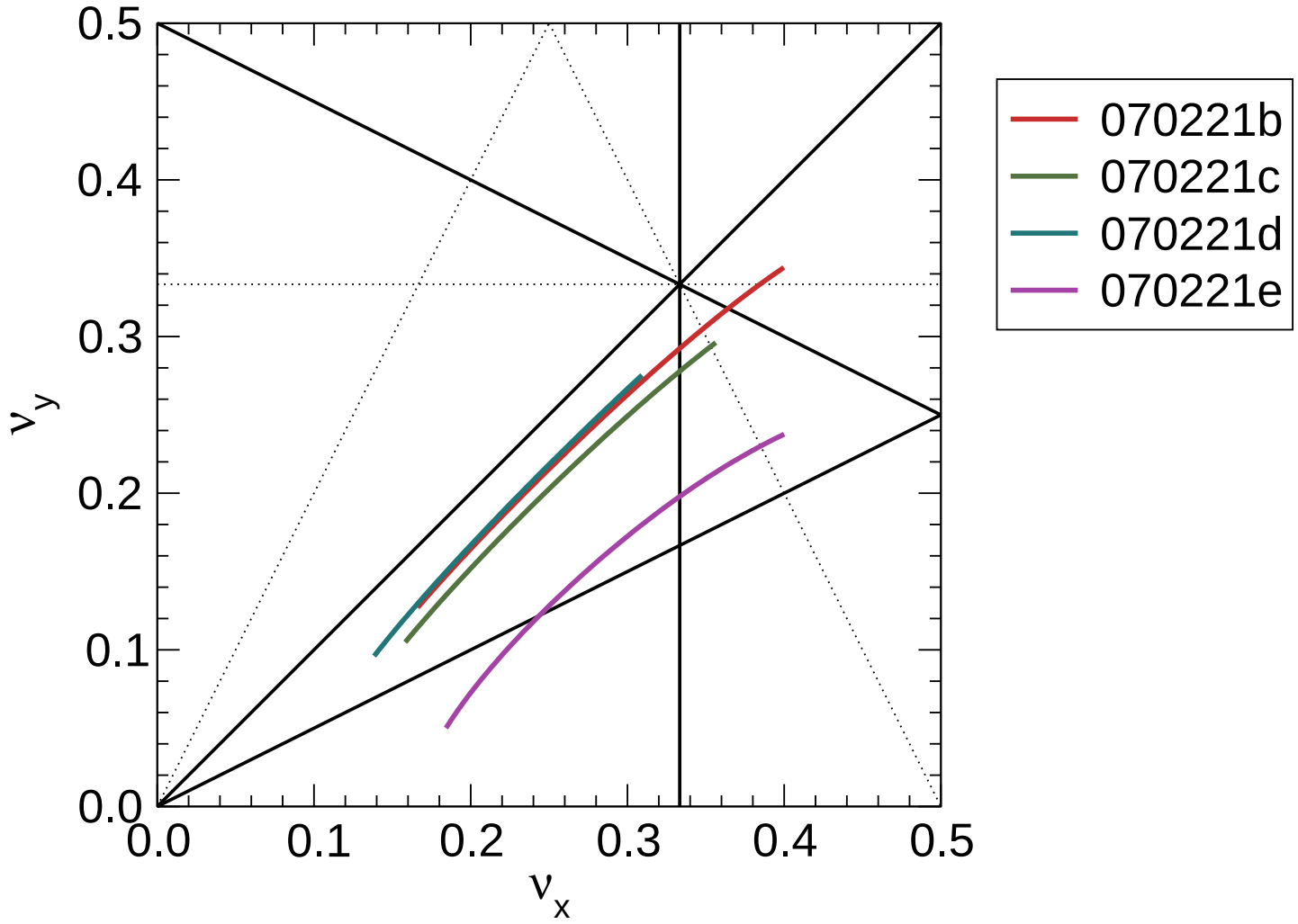
EMMA Experiment
Injection



EMMA Experiment
Tasks in Experiment

- Map tune and time of flight vs. energy
  - Inject at any energy!
- Adjust magnets to get desired tune/time
- Accelerate beam with different RF parameters
- Scan beam at large transverse amplitude
- Vary lattice to study
  - Effect of crossing different resonances
  - Long. dynamics from change in time of flight

EMMA Experiment
Tunes



Muon Collider Acceleration

- Many passes through RF
- FFAGs work better with small transverse emittance
- Fast ramping synchrotrons
  - High energy, may have time to ramp
  - Not exactly like usual synchrotrons
  - Some magnets ramp, others don’t
  - Keep time of flight constant during ramp
  - FFAG design techniques, but extra knobs